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CHARACTERIZATION, TAXONOMY AND MAPPING OF SELECTED SOILS OF SOUTH-WEST NIGERIA USING GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT
Information on soil properties and distribution is critical for making decisions with respect to crop production and other land use types. A field survey, morphological description and laboratory analyses of the soil samples collected were carried out to characterize, classify and map out selected soils of Akure area, South-Western Nigeria. Five representative pedons (EA1 to 5) were opened and described across the study site. The result revealed variation in morphological, physical and chemical properties of the soils. The texture of the surface soil across the study area was sandy loam overlying gravely sandy clay loam in pedons EA1 and 3, and sandy clay loam in the other pedons.
The soils are sandy loam overlying sandy clay loam in texture with silt/clay ratios greater than 0.25, indicating a low degree of weathering. They were strongly - slightly acid (4.9 to 6.2) and had very low (subsurface) to high (surface) organic carbon (2.54 to 20.0 gkg^{-1}). Three soil types, Plinthic Kandiustalfs, Typic Kandiustalfs and Aquic Kandiaqualfs were identified in the area based on the USDA soil Taxonomy and were correlated as Luvisols in World Reference Base. Generally, the soils differed in properties indicating their variation in productive potential and management requirements for specific agricultural use.

Keywords: Characterization, taxonomy, mapping, and crop production

Introduction

Understanding the distribution and properties of soils is necessary to planning and implementing sustainable land use and/or rehabilitation of degraded lands. Soil map has been identified as an interpretation of soils that occurred on a landscape and a very useful document in planning land use according to the soil's potential (Lobell *et al*., 2007). Okoye (1995) identified soil map of Nigeria as a very good, comprehensive and systematic effort to inventorize the soil resources of Nigeria and thus, could be used to assess the suitability of different soils for different uses. Analysis of soil maps as reported by Webb and Libume (2005) could indicate where there are uncertainties in mapping units consequent upon spatial variability in soil properties. The increasing use of simulation models developed to evaluate environmental impacts of land management practices had placed challenging demands on industrial soil maps and associated databases and that simulation models require quantitative soil data to represent soil characteristics for land areas.

Mapping of soils and delineation of farm boundaries had previously been carried out by several conventional methods. For instance, grid method of soil survey was used by Idoga and Azagaku (2005) to characterize and classify the soils of Janta area of Plateau State, Nigeria for sustainable rice production. The survey of soils of South-Western Nigeria was carried out by Smyth and Montgomery (1962), using parallel traverse grid to identify differences in soil associations as conditioned by topography. Adekayode (2003) used aerial photographs to report the influence of parent material on spatial distribution of soils and their associated characteristics. However, these conventional methods are labour intensive thereby, preventing mapping to be done within a short time frame and also could be devoid of high degree of accuracy. Over the past decade, the fields of earth observation and geo-information science have gradually moved away from the traditional mapping or 'inventory' type of science to focus increasingly on understanding the processes that shape our environment, predicting their future effects, and providing improved information to support planning and policy making. The technological advancements in the field of Geographical Information System have been a boon for such surveys (Manchanda *et al*., 2002). For optimum utilization of available agricultural land resources on a sustainable basis, timely and reliable information regarding their nature, extent and spatial distribution along with their potential and Limitations are very important. The efficiency and accuracy of data are improved when GIS data products are used.

The application of Geographic Information System (GIS) had been reported to enhance soil survey and the production of soil map. Brady and Weil (2012) discussed the findings of Potash and Phosphorus Institute (PPI) of Canada with the use of GIS to facilitate site specific nutrient management system studies. Adekayode (2006), in the research conducted on the application of GIS in mapping of soils of Owena forest reserve, Southwest Nigeria, concluded that GIS had added advantages of ease of sampling and quick results with higher degree of accuracy over the conventional methods. In spite of the fact that there is a desirable potentiality in the use of GIS in environmental monitoring in Nigeria as emphasised by Adedoyin and Adewale (1999), there has not been much work done in the use of GIS in soil studies particularly in Nigeria. The study was thus carried out to utilize the GIS in the classification and mapping of soils of Akure, South-west Nigeria underlain by the basement complex rock.

Materials and Methods

The study area

The study was conducted at Ipinsa in Akure – South Local Government Area of Ondo State, South-western Nigeria. The study site lies within latitudes 07° 19′ 16 - 50″ N and longitudes 05° 9′ 8 - 42″ E, covering about 85 hectares of land with altitudes ranging between 256 and 400 m above sea level. The site consists of gently undulating landscape developed on basement complex rocks comprising granites and gneisses (Ojanuga, 2006). Situated in the humid tropical rainforest, the mean annual rainfall of the study area ranges between 1500 and 1800 mm with distinct dry season of about 5 months occurring from November to March, and mean annual air temperature of 26.5º C. Dominant soil parent materials are the weathered remains of the varied basement complex rocks - granites and gneisses (Ojanuga, 2006). A wide range of crops such as grains, roots and tubers, legumes and vegetables are grown around the study location, among them are maize, sorghum, soy beans and yams.

Field work

A perimeter survey of the 85ha of land of the study area was carried out with the coordinates (latitudes and longitudes) and elevation data recorded with a hand held Global Positioning System (GPS) receiver (*Garmin-etrex*). Based on the data provided by the GPS and with the application of Arc map-10.2 software in GIS, the topographic map of the site was produced (Fig. 1). The topographic map was used as the base map for delineating soil boundaries. The soils were augered at the depth of 0 - 80 cm from the surface and observed for morphological properties like colour, texture and consistence. Based on auger investigations across the study location, five representative profiles (EA1 – 5) were established. Each profile pit was dug to the dimension of 2 m length x 1.5 m width x variable depth due to limitation encountered, demarcated into horizons and described for morphological attributes, following the procedures of the Soil Survey Staff (2014). Soil samples were collected from different identified genetic horizons for physical and chemical analyses.

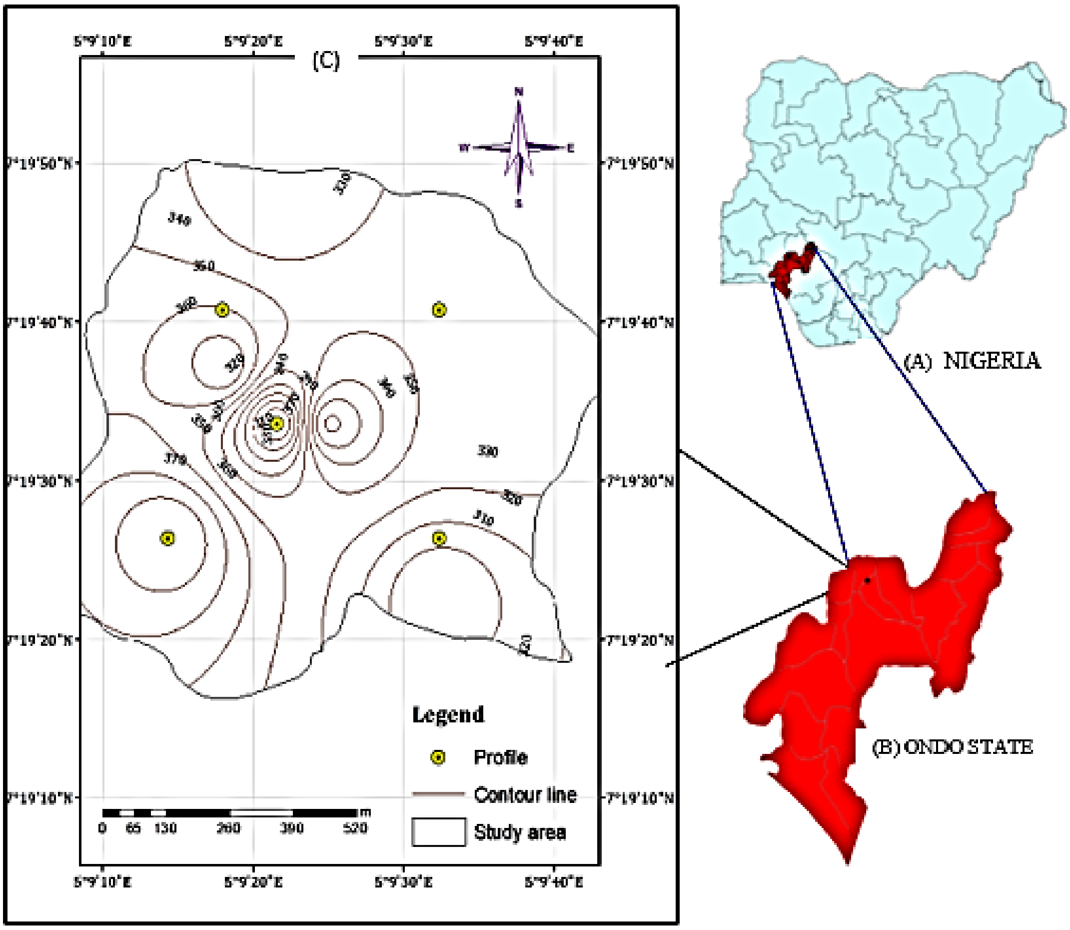

Fig.1: Map of Nigeria (A) showing the study area (B), and (C) topography of the study site with locations of profile pits sampled

Soil analysis and data interpretation

The soil samples collected were air-dried, gently crushed using a mortar and pestle, and passed through a 2 mm-sieve to obtain fine earth separates. Particle sizes larger than 2 mm were weighed as gravel content (G) and expressed as percentage:

$$\left\{\frac{weight\ of\ gravel}{Total\ \mathbf{weight}\ of\ the\ soil\ sample} \text{ X } 100\ \%\right\}. \quad \ldots\ldots . 1$$

The processed soil samples were analyzed for some physical and chemical properties following the procedures outlined by Udo, *et al*. (2009) as briefly highlighted herein. Particle size analysis was determined by the Bouyocous hydrometer method while soil pH H_2O suspension was determined with pH meter. Organic carbon (OC) was by Walkley-Black method. Available P was determined by the Bray P 1 method and total nitrogen (TN) by Kjeldahl method. Exchangeable bases, calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+) were extracted with neutral ammonium acetate (1N NH_4OAc) solution and amounts in solution measured by atomic absorption spectrophotometry. Cation exchange capacity (CEC) was determined by the neutral 1 N NH_4OAc (pH 7.0) saturation method, while percent base saturation was by calculation. The exchangeable acidity, that is, hydrogen (H^+) and aluminum (Al^{3+}) was determined by titrimetric method. The results of the laboratory analyses were interpreted based on the methods of Chude, *et al*. (2011) and Hezelton and Murphy (2011).

Soil classification

Based on the morphological (field data), physical and chemical (laboratory data) properties obtained, the soils were classified using the USDA Soil Taxonomy System (Soil Survey Staff, 2014) and correlated with World Reference Base for soil resources (WRB, 2014).

Production of soil map

Based on the extent to which the properties of the pedons meet the criteria for soil classification (Tables

1 and 2), and with respect to the coordinates of the sample locations, the thematic layer was prepared according to the soil classes identified. All the scaled thematic layers were assigned weighted values and integrated into map algebra using kriging interpolation provided in Arc Map 10.2 software of GIS to produce soil maps of the site under study (Fig. 2).

Results and Discussion

A. Morphological and Physical Characteristics

Data on some morphological and physical properties of the soils are shown on Table I. The surfaces of EA1 to EA4 were characterized by a dark brown (7.5YR3/2) colour which graded to various shades of strong brown in the subsurface, whereas EA5 had dark grayish brown (10YR 4/2) colour at the surface over grayish brown (10YR5/2) and light brownish gray (10YR6/2) subsurface. The surface horizons of all the pedons were mottle-free, an indication of good surface drainage as evidenced by the various degrees of strong brown colouration. This may be attributed to perhaps, presence of sesquioxides in hydrated form, especially the goethite. However, the occurrence of yellowish red (5YR 5/6) mottles coupled with the grayish colouration of EA5 was an indication of imperfectly or poorly drained condition of the pedon (Esu, 2010). The surface soil was weak and crumb-structured over moderate and sub-angular structured subsurface. Absence of cracks on the surfaces of the pedons probably inferred that the soils have non-expanding clay minerals e.g. kaolinite in them (Chude, *et al.*, 2011; Soil Survey Staff, 2014). Gravels probably made of Fe and manganese (Mn) concretions were common in sub-surface horizons of EA1 and 3 consequently, may impede plant root development and water movement as they harden up to form hardpans. This corroborates the work of Babalola (1980), which reported that hardpans and concretions impede drainage with accumulated water resulting in aeration problem. The friable consistence of the epipedons was an indication of good tillage operation and easy penetration of plant roots. Ojeniyi (2002) reported that a friable soil often has the optimum conditions for tillage operations, resulting in better seedbed preparation with good drainage, gaseous exchange and heat conductance. The texture of the surface soil across the study area was sandy loam overlying gravely sandy clay loam in pedons EA1 and 3, and sandy clay loam in the other pedons. Sand dominated the mineral fraction in all the landscape positions studied which may be partly attributed to parent material rich in quartz mineral, an essential component in granite (Wilson, 2012)], and partly to geological processes involving sorting of soil materials by biological activities, clay migration through eluviation and illuviation, or surface erosion by runoff or their combinations (Malgwi, *et al.*,2000 and Akinbola, *et al*., 2009. Conversely, there was a progressive increase in clay content down the pedal depth. The marked clay increase in the Bt horizons was an evidence of eluviation – illuviation soil forming process resulted from high and intense rainfall experienced in the area, coupled with network of pores of the sand texture of the upper horizons that encouraged easy migration of clay (fine texture) in suspension down the profile (Amusa, *et al.*, 1995, Malgwi, *et al*., 2000, Tripathi, *et al.*, 2006).

The distribution of silt within the subsoil of the pedons was irregular. The average silt/clay ratio values were 0.41, 0.39, 0.38, 0.41 and 0.47 respectively for EA1 to 5. This was an indication that the soils studied are relatively young. Silt/clay ratio of < 1.00 could mean that these soils had undergone ferralitic pedogenesis (Lawal, *et* al., 2013), or the low silt/clay ratio probably implied that these soils still have weather-able minerals in them. This is also in alignment with Ayolagha and Opene, (2012) who reported that, old parent materials usually have silt/clay ratios below 0.15 while silt/clay ratios above 0.15 indicate 'young' parent materials. More so, the soils with silt/clay ratios less than 0.25 are at the advanced stage of weathering while those with ratios greater than 0.25 indicate a low degree of weathering.

B. Chemical properties of the soils

Table 2 shows the chemical properties of the pedons studied. The soils studied fall within the very strongly to slightly acid class (Chude, *et al*., 2011 and Sasseville, 2013), with pH (H_2O) values ranging from 4.9 to 6.2. The pH decreased with soil depth. Generally, the surface horizons of the pedons were medium to slightly acid (pH 5.5 - 6.2), while B and C-horizon were strong to very strong acid with pH values ranging from 4.9 - 5.4. The acid nature of the soil can be ascribed to high rate of leaching of bases which is prevalent in the humid tropics. Chude, *et al.* (2011) and Sasseville, 2013 had established pH range of 5.5 - 7.0 (slightly acid to neutral reaction) as optimal for overall satisfactory availability of plant nutrients. This implies that the soils of the study site are ideal for most crops to thrive well as soil nutrient elements will be readily available for absorption by plant at this pH range. Organic carbon content of the surface horizons of the pedons ranged from 15.7 to 20.0 gkg^{-1} (Table 2) and decreased with soil depth. The subsurface horizons were generally lower in organic matter than the surface horizons of all the pedons examined. The reasons for this may be adduced to the fact that the surface horizons are the points where decomposition and humification of organic materials take place. The relatively high organic carbon in the soils studied, regardless of high temperature and humidity of the area could be attributed to the vegetal cover from bush re-growth (three seasons fallow) and the fact that the soils have not been subjected to the degrading effect of continuous cultivation. Available phosphorous content of the soils varied from 7.2 to 19.3 $mgkg^{-1}$ in all the horizons with irregular distribution across the depths. The available P values in the location are considered moderate as they are within the range recommended for most commonly cultivated crops (Chude, *et al.*, 2011). Generally, there was low accumulation of bases in the horizons of the soil except pedons EA2, EA4 and EA5 where exchangeable K^+ was rated moderate across the horizons. The low level of bases in these soils could suggest that leaching is a marked pedogenic process, resulting from the high sand proportion in the area (Amusan, *et al*., 2006). The cations exchange capacity (CEC) was generally low with values ranging from 3.06 to 4.26 cmol (+) kg^{-1}. The low CEC could be attributed, as observed by Fasina *et al.* (2007) to the Kaolinitic nature of the parent material from which the soils have developed. This is also corroborated by Nnaji, *et al*., (2002) that, low CEC of a soil could be because of clay type content, high rainfall intensity as well as previous land use. Base saturation was moderate and was a reflection of concentration of basic cations at the exchange complex site (Atofarati, *et al.*, 2012).

Classification of Soils

The soils across the study area represented by pedons EA1 – 5 were classified (Soil Survey Staff, 2014) and correlated (WRB, 2014). Clay (or soil colloid) movement or accumulation has been clearly demonstrated by the particle size data (Table 1). This signifies the presence of argillic or kandic horizons established in all the pedons because they meet the following requirements: coarser-textured surface horizons over vertically (morphologically) continuous subsurface horizons; CECs within subsurface B horizons that are less than 12 cmol(+)kg^{-1} clay; a regular decrease in organic carbon content with increasing depth; and all these in addition to the requirement of clay content which progressively increased with depth (Tables 1 and 2) (Soil Survey Staff 2014). However, Pedon FP5 has identical diagnostic properties as other pedons except for the aberrant horizons (54–110 cm, Table 1) that have slight decrease in clay content after a regular decrease with increasing depth. Nevertheless, the dominating surface charge property indicator (low CEC) confirms the presence of a kandic horizon in the pedon. The evidence of argillic horizons coupled with high base saturation (> 50% by NH_4OAc at pH 7.0) classifies the pedons into the order Alfisols. The prevalent ustic moisture regime (soils are dry for more than 90 cumulative days but less than 180) in the Alfisols places the soils in the sub-order Ustalfs. The upland soils of South Western Nigeria are primarily under ustic moisture regime (Periaswamy and Ashaye, 1982). However, pedon EA5 qualifies as Aqualfs because of the gleyed subsurface horizons. The presence of kandic horizon places pedons EA1 - 4 in the great group Kandiustalfs and pedon EA5 Kandiaqualfs. The presence of five percent or more (by volume) plinthite in the horizons of pedons EA1 and 3 within 150 cm of the mineral soil surface classifies them into the sub-group Plinthic Kandiustalfs. Soils of Pedons EA2 and 4 have no evidence of hydromorphic properties within 150 cm of the mineral soil surface. These soils therefore, classify as Typic Kandiustalfs. Soils of pedon EA5 show evidence of redox depletion in its sub-surface (at the depth of 54 - 110 cm of the mineral soil surface) and therefore, qualify as Aquic Kandiaqualfs. The soil map showing the classification of soils in the study location is presented in fig. 2.

Conclusion

The subsurface horizons of the soils studied were well drained except pedon EA5 which was imperfectly drained due to influence of water-table. The poor internal drainage properties of pedon EA5 and the occurrence of gravels in the subsurface horizons of AE1 and 3 may affect choice of deep rooted crops except measures to correct the problems of drainage and gravel are introduced. Cultural practices that would prevent erosion are essential on EA1 and 3 in order not to expose the plinthite layer. It is important to monitor pH of the soils to avoid fixing of phosphorus which at the time of this study was adequate for arable crops production. Further decrease in pH value of these soils may accelerate iron solubility/ activity which may advance the plinthization in EA1 and EA3. Maintenance of high organic matter level in the soil and proper drainage to improve the structure of soils are equally essential for a sustained crop production in the study area.

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Table 1: Some morphological and physical properties of the soils

Pedon	Horizon Design	Soil Depth(cm)	Colour (moist) Matrix	Mottling	Structure	Gravel (gkg^{-1})	Texture (gkg^{-1}) Sand	Silt	Clay	Texture	Silt/Clay
FP1	Ap	0-11	7.5YR 3/2	-	1cr	15	795	73	133	SL	0.55
	Bc	11-30	7.5YR 4/4	-	2sbk	29	720	75	205	GSCL	0.37
	C	30-93	7.5YR 5/8	-	2sbk	46	667	83	250	GSCL	0.33
FP2	Ap	0-15	7.5YR 3/2	-	1cr	08	786	80	134	SL	0.60
	Bt1	15-40	7.5YR 4/3	-	2sbk	10	705	75	220	SCL	0.34
	Bt2	40-75	7.5YR 5/6	-	2sbk	12	625	95	280	SCL	0.34
	BC	75-175	7.5YR 4/6	-	2sbk	16	540	100	360	SC	0.28
FP3	Ap	0-8	7.5YR 4/2	-	1cr	13	810	65	125	SL	0.52
	Bc	8-26	7.5YR 5/3	-	2cr	28	710	70	220	GSCL	0.32
	C	26-85	7.5YR 4/6	-	2sbk	40	650	80	270	GSCL	0.30
FP4	Ap	0-17	10YR 5/2	-	1cr	07	770	80	130	SL	0.62
	Bt1	17-41	10YR 5/3	-	2sbk	13	730	68	202	SCL	0.34
	Bt2	41-88	10YR 5/3	-	2sbk	12	660	90	250	SCL	0.36
	BC	88-186	10YR 5/3	-	2sbk	15	580	100	320	SC	0.31
FP5	Ap	0-26	10YR 4/2	-	1cr	03	783	85	132	SL	0.64
	Bt	26-54	10YR 5/2	5YR 5/8	2sbk	07	710	80	210	SCL	0.38
	Bg1	54-76	10YR 6/3	5YR 5/8	2sbk	12	750	70	180	SL	0.39
	Bg2	76-110	10YR 6/3	5YR 5/8	2sbk	10	730	85	185	SL	0.46

SL= sandy loam; SCL= sandy clay loam; GSCL= gravely sandy clay loam

Table 2: Some chemical properties of the soils

Pedon	Horizon Design	Soil Depth (cm)	pH (H_2O)	OC (gkg^{-1})	TN (gkg^{-1})	Av.P ($mgkg^{-1}$)	Exch ($cmolkg^{-1}$) Ca^{2+}	Mg^{2+}	K^+	Na^+	Acid	CEC ($cmolkg^{-1}$)	BS (%)
FP1	Ap	0-11	5.5	15.23	0.78	7.50	1.65	0.65	0.29	0.23	0.82	3.72	78.00
	Bc	11-30	5.4	9.12	0.37	8.10	1.74	0.51	0.23	0.20	1.47	4.26	62.91
	C	30-93	5.2	3.78	0.22	7.20	1.73	0.52	0.20	0.21	1.55	4.23	63.40
FP2	Ap	0-15	6.2	28.94	1.36	19.30	1.35	0.60	0.34	0.29	0.73	3.23	61.10
	Bt1	15-40	5.4	6.26	0.21	9.20	1.43	0.48	0.30	0.17	0.92	3.30	77.40
	Bt2	40-75	5.2	5.03	0.19	12.30	1.88	0.68	0.32	0.19	0.84	3.81	72.10
	BC	75-175	4.9	2.54	0.11	10.50	1.36	0.60	0.29	0.29	1.61	4.15	78.00
FP3	Ap	0-8	5.8	15.73	0.65	7.20	1.54	0.61	0.29	0.29	0.77	3.50	78.00
	Bc	8-26	5.4	6.51	0.32	7.70	1.64	0.48	0.29	0.22	1.38	4.01	65.60
	C	26-85	5.3	5.55	0.10	7.40	1.62	0.49	0.20	0.22	1.46	3.99	63.40
FP4	Ap	0-17	5.9	20.07	1.22	11.30	1.48	0.64	0.33	0.32	0.59	3.36	82.40
	Bt1	17-41	5.4	10.61	0.25	9.93	1.59	0.57	0.34	0.32	0.80	3.62	77.90
	Bt2	41-88	5.0	4.64	0.09	7.53	1.59	0.55	0.44	0.41	1.43	4.31	66.80
	BC	88-186	5.3	2.12	0.07	7.57	1.92	0.55	0.44	0.39	0.92	4.22	78.20
FP5	Ap	0-26	5.6	19.77	1.18	10.40	1.35	0.59	0.30	0.29	0.54	3.06	82.70
	Bt	26-54	5.2	10.31	0.30	9.20	1.45	0.52	0.30	0.29	0.73	3.30	77.90
	Bg1	54-76	5.4	4.17	0.12	7.60	1.45	0.49	0.31	0.37	1.31	3.93	66.70
	Bg2	76-110	5.0	3.37	0.09	9.80	1.83	0.60	0.38	0.22	1.54	4.57	66.30

OC= organic carbon; TN=total nitrogen; Av.P= available phosphorus; Exch. = exchangeable; CEC=cation exchange capacity; BS=base saturation

Table 3: Critical limits for interpreting fertility levels of analytical parameters for Nigeria soils

	Very Low	Low	Moderate	High	Very High
Organic Carbon (%)	< 0.4	0.4 – 1.0	1.0 - 1.5	1.5 – 2.0	> 2.0
Total N (%)	< 0.05	0.05 – 0.15	0.15 – 0.25	0.25 – 0.30	> 0.30
Available P (mg/kg)	< 3.0	3.0 – 7.0	7.0 – 20.0	> 20.0	-
Exch. K (cmol/kg)	< 0.2	0.2 – 0.3	0.3 – 0.6	0.6 – 1.2	> 1.2
Exch. Na (cmol/kg)	< 0.1	0.1 – 0.3	0.3 – 0.7	0.7 – 2.0	> 2.0
Exch. Ca (cmol/kg)	< 2.0	2.0 – 5.0	5.0 – 10.0	10.0 – 20.0	> 20.0
Exch.Mg (cmol/kg)	< 0.3	0.3 – 1.0	1.0 – 3.0	3.0 – 8. 0	> 8.0
CEC (cmol/kg)	<6.0	6.0 – 12.0	12.0 – 25.0	25.0 - 40	> 40
Base Saturation (%)	0 - 20	20 - 40	40 - 60	60 - 80	90 – 100

Soil Depth (cm)	**Soil Reaction (H_2O)**	
	(Acid)	***(Alkaline)***
Very shallow: < 30	Extremely acid: < 4.5	Neutral (6.6 – 7.2)
Shallow: 30-50	Very strongly acid: 4.5 - 5.0	Very strongly alkaline (> 9.0)
Moderate: 50 - 100	Strongly acid: 5.1 - 5.5	Strongly alkaline (8.5 – 9.0)
Deep: > 100	Moderately acid: 5.6 - 6.0	Moderately alkaline (7.9 – 8.4)
	Slightly acid: 6.1 - 6.5	Slightly alkaline (7.3 - 7.8)

Sources: (Enwezor *et al.*, 1989; Esu, 2010; Chude *et al.*, 2011; Hezelton and Murphy, 2011; Sasseville, 2013).

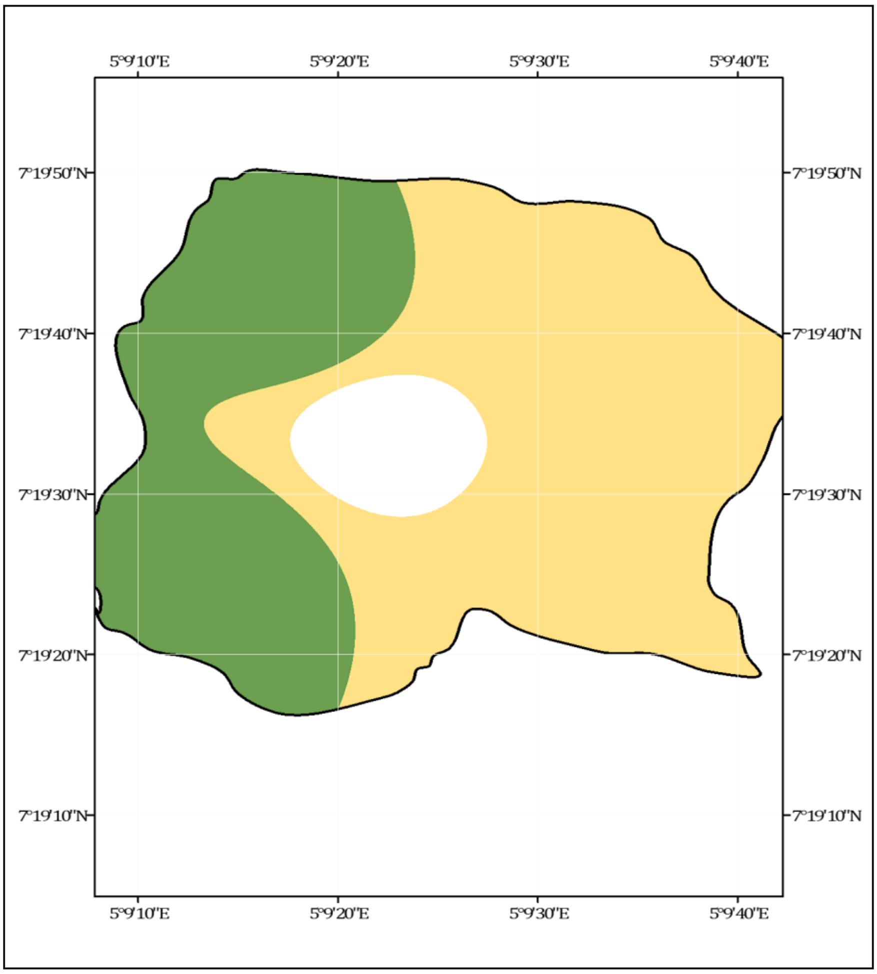

Fig. 2: Soil map of the study area